Passive Four-Pole Admittances of Microwave Triodes

By SLOAN D. ROBERTSON

Measurements have been made of the passive, four-pole admittances of parallel-plane triodes over a wide range of cathode-to-grid and grid-to-plate spacings at a frequency of 4060 megacycles. Results are given for a parallel wire grid and a cross-lateral grid. The microwave transadmittances are found to be much higher than the values measured at low frequencies.

DURING the course of an experimental study of the active four-pole admittances[1] of the 1553 close-spaced triode,[2] a question arose as to whether the grid wires were introducing any appreciable inductance or resistance in the circuit used for measurement. It appeared necessary, therefore, to learn something of the passive four-pole parameters of the triode in order to separate the electronic from the passive admittances. It was generally believed that the electrostatic analyses of the passive admittances which have been successfully applied at the lower frequencies would no longer be valid with close-spaced structures at microwave frequencies. For example, it was considered possible that the grid wires themselves might possess an effective inductive reactance, so that the admittances between the grid and cathode or between the grid and anode might not be equal to the values computed from the electrostatic capacitances. Moreover, it was thought likely that energy might be transmitted from the cathode-grid region to the cathode-plate region or vice versa, not only by the medium of the electrostatic coupling, but also by means of an electromagnetic coupling through the grid. The measurements to be reported below indicate that the first of these conjectures was false, but that the second was true.

In view of the lack of available information on these questions in general, it seemed highly desirable to employ the available measuring equipment, not only to determine the passive parameters of a triode having electrode spacings corresponding with those of the 1553, but to extend the scope of the measurements to include a wide range of electrode spacings in order that the results would be of more general interest.

Although these measurements were in principle very simple, in practice the mechanical problem of achieving the desired degree of accuracy proved rather difficult. It was required that the cathode, grid, and anode planes be almost perfectly parallel and that the spacings between them be adjustable

[1] S. D. Robertson, "Electronic Admittances of Parallel-Plane Electron Tubes at 4000 Megacycles," this issue of the *B. S. T. J.*

[2] J. A. Morton, "A Microwave Triode for Radio Relay," *Bell Laboratories Record*, Vol. XXVII, No. 5, pp. 166–170, May 1949.

to specific values witb a high degree of precision. In order to equal the dimensional tolerances of the 1553 it was necessary that parallelism and spacing he accurate to 0.1 mil.

A schematic diagram of the apparatus is shown in Fig. 1. A flat, circular disc having a 250-mil diameter aperture, across which the grid was stretched, was mounted upon the face of the hollow micrometer screw #1. The latter was mounted so that its face was accurately parallel with the end face of the central conductor of the input coaxial line in the upper part of the figure. By means of the micrometer #1 the input spacing S_1, which we shall consider as representing the catbode-grid spacing, could be adjusted. The central conductor of the coaxial line was insulated at d.c. from the outer conductor; hence it was possible to use an ohmmeter to indicate when the grid was just touching tbe coaxial face. The micrometer could then be hacked away from the grid by any desired amount. The input coaxial was fitted with a standing wave detector in the form of a prohe which could he moved along the line and placed at any arbitrary distance h from the grid.

On the output side of the circuit, in the lower part of the figure, there was another coaxial line arranged so that its center conductor could be driven by micrometer #2. The latter was insulated from tbe outer conductor of the coaxial by means of a condenser in order that an ohmmeter could he used to determine the position of the micrometer which caused the central conductor to just touch the grid. Spacing S_2 could then be adjusted. The output coaxial line was terminated in its characteristic impedance of 62 ohms. At a distance of $\lambda/2$ from the grid a prohe was located for sampling the power in the output line.

The diameter of the input coaxial conductor was 180 mils at the end. In the figure it will be noted that at a short distance from the end the diameter increased to a larger diameter (250 mils). Because of the required length of the central conductor, it was necessary to increase its size in this way for mechanical rigidity. The effect of this change in cross-section was computed and allowed for in the final results. The output coaxial conductor was relatively short, so that it was possible to assign a diameter of 180 mils for its entire length. The 180-mil diameter was selected to correspond with the diameters of the cathode and anode in the 1553 triode.

The procedure for making the measurements was as follows: With a particular set of spacings S_1 and S_2 the standing wave ratio in the input line was measured. This ratio, together with the measurement of the position of a standing wave minimum, permitted the calculation of an input admittance Y to he made. Then with the standing wave detector prohe placed at a distance $h = \lambda/2$ from tbe grid, the ratio of the voltage at the input terminals of the triode to the voltage appearing at the output probe was measured hoth as to magnitude and phase as descrihed in a recent

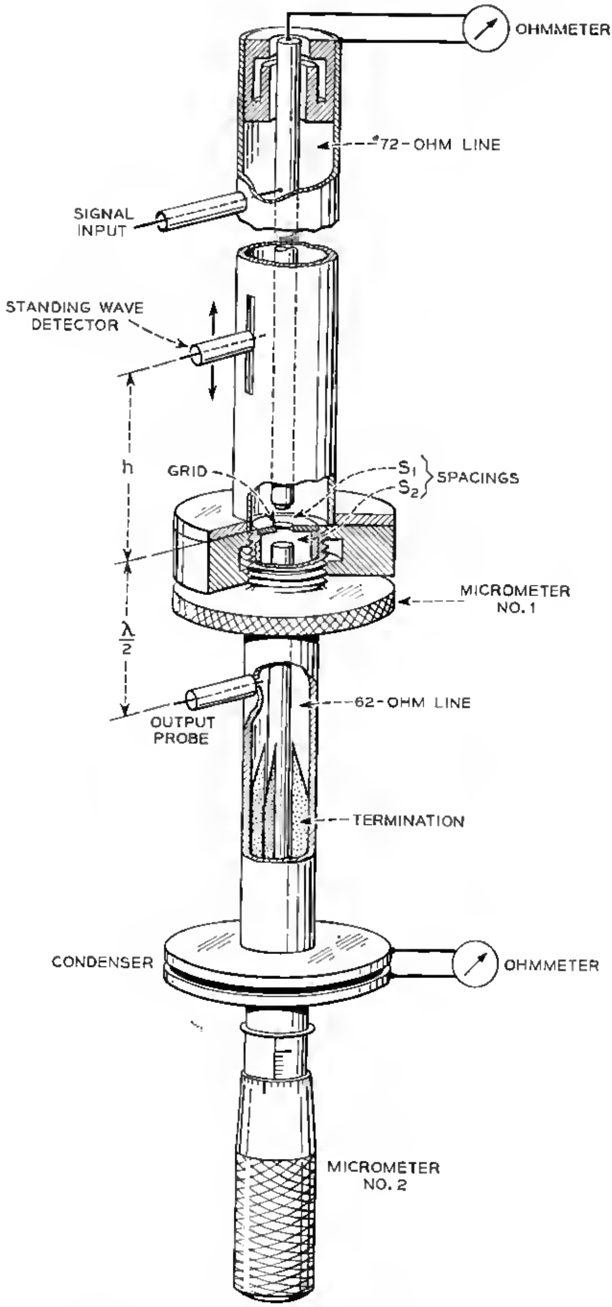

Fig. 1—Apparatus for measuring passive admittances of triode.

paper.[3] This quantity will be called γ. These measurements were sufficient for an evaluation of the four-pole parameters of the structure. All measurements were made at a frequency of 4060 megacycles.

The equivalent circuit of the passive triode structure is shown in Fig. 2. The desired parameters are y_{11}, y_{12}, and y_{22}. The following equations indi-

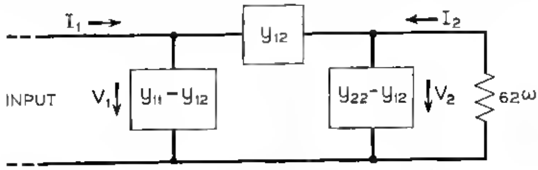

Fig. 2—Equivalent passive circuit of a triode.

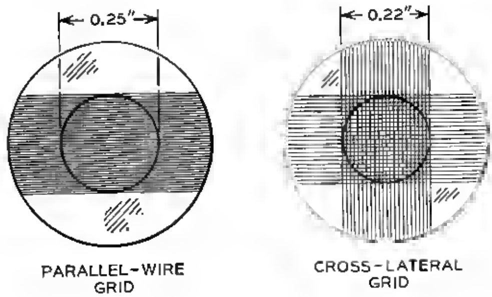

Fig. 3—Types of grids used in the measurements.

cate the relation between these parameters and the measured quantities Y and γ:

$$y_{11} = Y + \frac{62y_{12}^2}{62y_{22} + 1} \approx Y \tag{1}$$

$$y_{12} = \frac{y_{22}}{\gamma}\left[1 + \frac{1}{62y_{22}}\right] \tag{2}$$

where the number 62 represents the output terminating impedance. For all cases to be described here the second term on the right side of Equation 1 is small in comparison with Y. This is a result of the small values encountered for y_{12}. To a good approximation y_{11} is equal to the measured input admittance Y. This was verified by observing the variation in input admittance as the output spacing was varied while keeping the input spacing fixed. Only a slight variation in admittance was observed, which indicated that the fractional term in Equation 1 was small in comparison with Y.

Suppose, then, that for a given input and output spacing S_1 and S_2,

[3] "A Method of Measuring Phase at Microwave Frequencies," S. D. Robertson, *Bell System Technical Journal*, Vol. XXVIII, No. 1, pp. 99–103, January 1949.

Y and γ are known. y_{22} can readily be determined by readjusting the input spacing to equal the output spacing and measuring a second admittance Y'. y_{22} will be approximately equal to this value. There is, then, sufficient information to compute y_{12}.

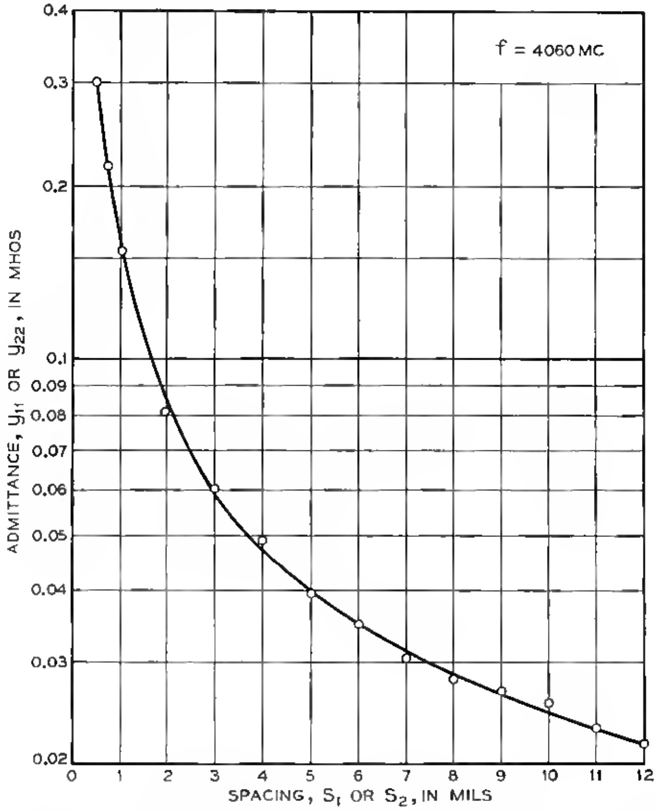

Fig. 4—Variation of passive input and output admittances with spacing.

Two grids were used in this work. The first was a parallel wire grid of 0.3 mil tungsten wire wound at 1000 turns per inch. The second was also of 0.3 mil tungsten wound in a crisscross fashion at 550 turns per inch. Both grids are shown in Fig. 3. It will be noted that the cross-lateral grid has an aperture 220 mils in diameter.

The values of y_{11} and y_{22} were found to be almost purely capacitive and were the same for both types of grid. These values are shown in Fig. 4. y_{11} and y_{22} correspond to capacitances C_{11} and C_{22}, which agree surprisingly well with the calculated capacitances between the grid and cathode, and grid and plate planes, respectively. Figure 5 shows the experimentally

determined values of C_{11} and C_{22} plotted as a dashed curve. The theoretical values (neglecting fringing capacitance) are shown by the solid curve. Since fringing was neglected, it is not surprising that the measured capacitances should exceed the calculated values by the amount shown.

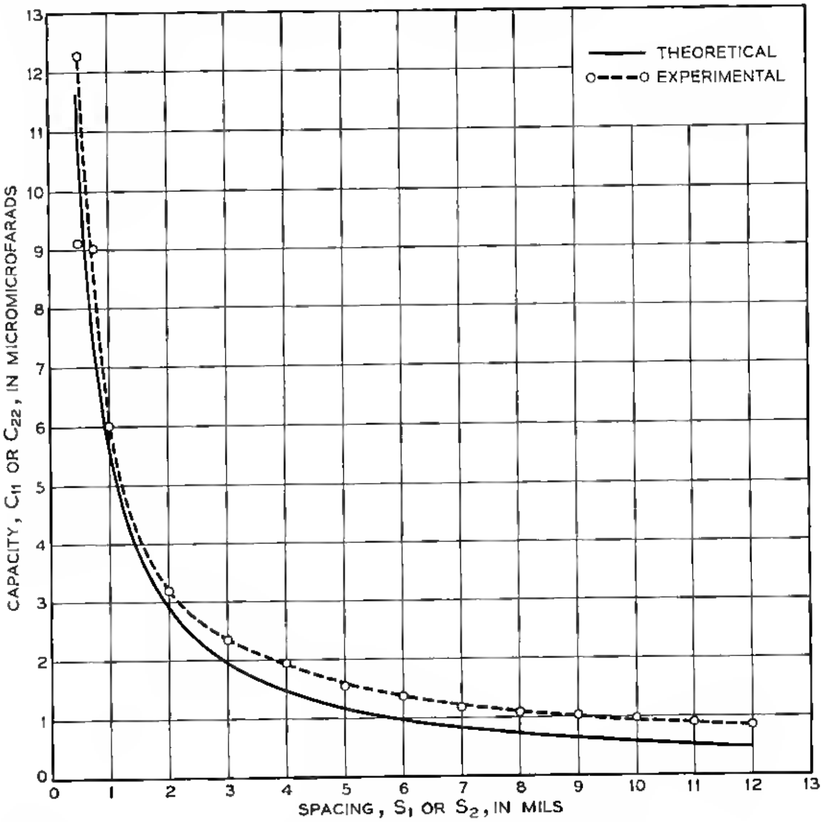

Fig. 5—Comparison of theoretical and experimental values of input and output capacitances.

The magnitudes of y_{12} for each grid over a range of values of S_1 and S_2 are shown in Figs. 6 and 7. It will be noted that, for a given set of spacings S_1 and S_2, y_{12} is much greater for the parallel wire grid than for the cross-lateral. This is the sort of result one would expect if y_{12} resulted from electromagnetic coupling through the grid, since the parallel wire grid would be expected to offer a better transmission path than the cross-lateral grid. It was not practicable with the equipment used in these experiments to measure the values of y_{12} at low frequencies where y_{12} would be determined by the cathode-plate capacitance. Data were available, however, for the low-frequency, cathode-plate capacitance of the standard, parallel-wire

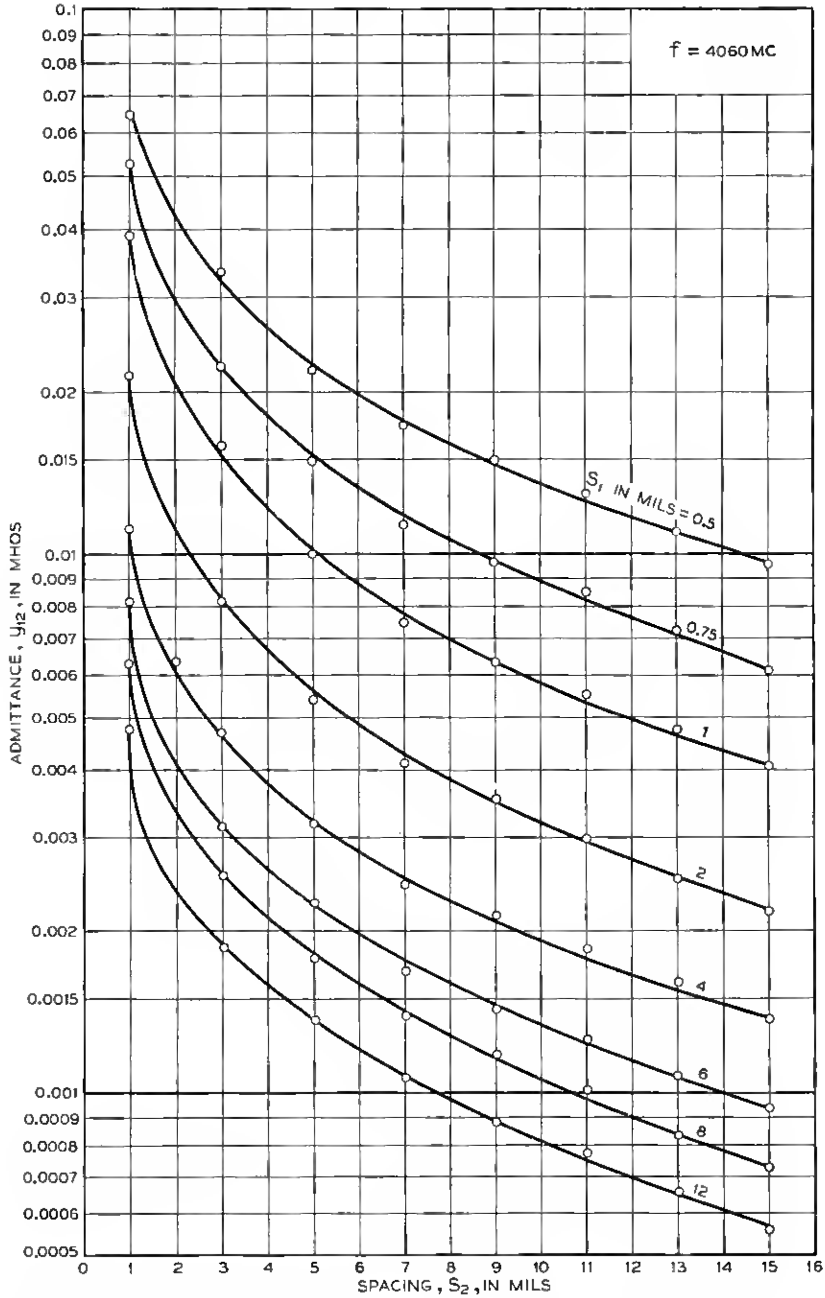

Fig. 6—Passive transadmittances of a triode having a parallel wire grid of 0.3 mil wire wound at 1000 turns per inch.

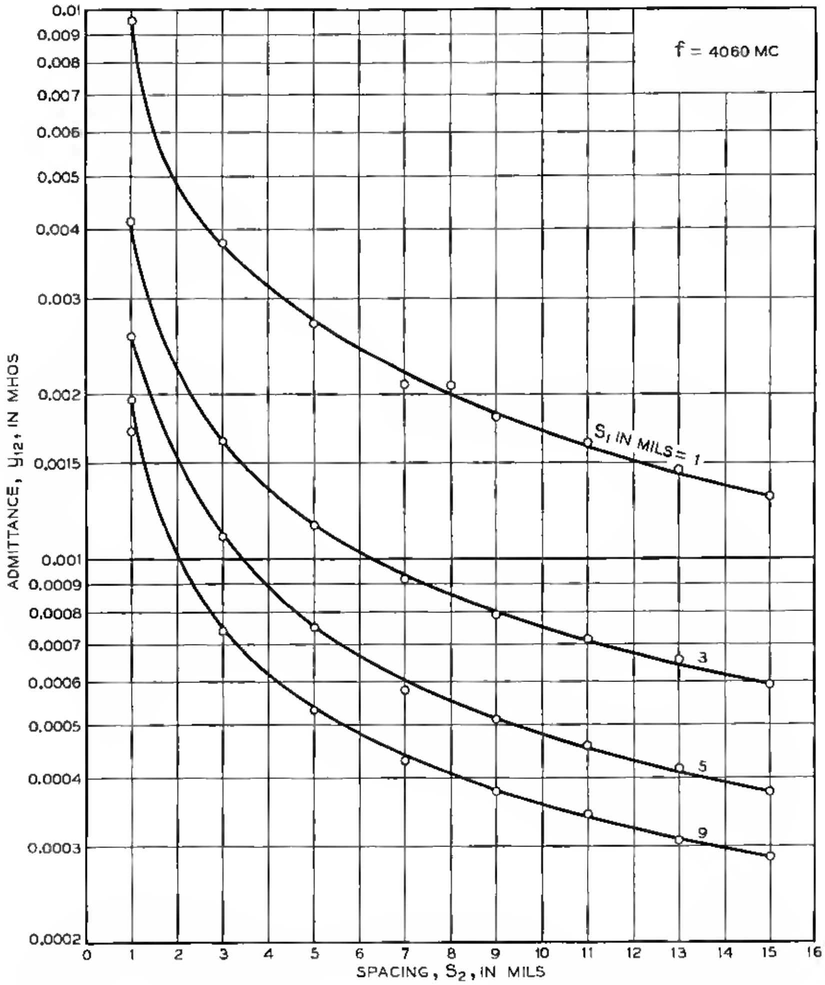

Fig. 7—Passive transadmittances of a triode having a cross-lateral grid of 0.3 mil wire wound at 550 turns per inch.

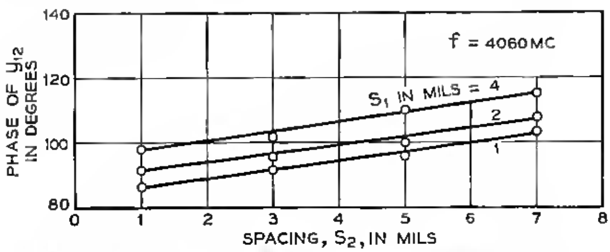

Fig. 8—Phase of the transadmittance of the parallel-wire grid.

grid, 1553 triode having input and output spacings of 0.5 and 12 mils respectively. The capacitances averaged about 0.008 $\mu\mu$f, which would correspond to a value of y_{12} of 0.0002 mho at 4060 megacycles. The latter is about 50 times lower than the measured 4060 megacycle value. Evidently, therefore, electromagnetic coupling plays a dominant role.

Reciprocity should give a reasonable idea of the accuracy of these measurements. Thus, for $S_1 = 0.001''$ and $S_2 = 0.012''$, one would expect the same y_{12} as for the case where $S_1 = 0.012''$ and $S_2 = 0.001''$. An examination of the data will indicate that the reciprocal differences are of the order of 10% in some cases. These differences may be partly the result of the change in line cross section encountered in going from tbe input to the output. Tbat is to say, the two cases being compared are not quite reciprocal in geometry.

Figure 8 sbows the phase of y_{12} for the parallel wire grid. Because of tbe low transmission through the grids there was not sufficient energy to determine the transfer phases with any very great accuracy, particularly for wide spacings in the case of the parallel wire grid and for all spacings in the case of the cross-lateral. Consequently, Fig. 8 shows only those results which are believed to be reasonably accurate.

The autbor wishes to acknowledge tbe contribution of Mr. F. A. Braun who ably assisted in this work.